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RESEARCH REPORT

INTEROPERABILITY ISSUES IN THE USE OF
SATELLITE-BASED NAVIGATION SYSTEMS FOR
CIVIL AVIATION PURPOSES

MR. MARCOS COSTILLA, FAA

1989

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AIR UNIVERSITY
UNITED STATES AIR FORCE
MAXWELL AIR FORCE BASE, ALABAMA

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INTEROPERABILITY ISSUES IN THE
USE OF SATELLITE-BASED NAVIGATION
SYSTEMS FOR CIVIL AVIATION PURPOSES

by

Marcos Costilla

FAA

A DEFENSE ANALYTICAL STUDY SUBMITTED TO THE FACULTY

IN

FULFILLMENT OF THE CURRICULUM

REQUIREMENT

Advisor: Col. Eric Sundberg

MAXWELL AIR FORCE BASE, ALABAMA

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EXECUTIVE SUMMARY

TITLE: Interoperability Issues in the Use of
Satellite-Based Navigation Systems for Civil Aviation
Purposes

AUTHOR: Marcos Costilla, FAA

This study analyses the compatibility and interoperability issues related to the use of the USAF NAVSTAR Global Positioning System (GPS) for civil aviation purposes. It also compares the USSR GLONASS navigation system to GPS to provide similar services worldwide.

The GPS is primarily a military asset with significant civil applications especially as it applies to air traffic control. It is recognized by the civil sector as a system which will revolutionize the present day navigation methodology and indeed make way for new ATC concepts and procedures. For the military, it is a vital link in its support of the strategic modernization program.

The FAA is the lead agency in establishing the standards and procedures necessary to integrate GPS as a sole means navigation aid into the National Airspace System (NAS). These efforts are continuing in cooperation with the USAF GPS JPO. The Joint DOD/DOT Federal Radionavigation Plan, fourth edition, attests

to this joint effort. Several compatibility and interoperability issues are described in this study wherein the system integrity issue remains outstanding and must be resolved prior to using GPS for civil aviation.

In summary, it appears the USAF and FAA intend to utilize GPS to meet their air navigation system requirements of the future. However, the USAF GPS program implementation is years ahead of the FAA. It is recommended the programs be compared and evaluated to ensure maximum compatibility and to expedite the use of GPS for civil applications.

FAA is presently working with the USSR and the International Civil Aviation Organization (ICAO) in an effort to develop international standards for satellite-based navigation systems such as GPS and GLONASS. This effort appears to be progressing well in spite of limited data regarding the GLONASS system.

BIOGRAPHICAL SKETCH

Mr. Marcos Costilla, GM-15, joined the Federal Aviation Administration in 1970. His most recent assignment, prior to attending the Air War College, was that of Aviation Systems Advisor in Madrid, Spain, 1984-88. He has held FAA supervisor/manager positions since 1976 in Boca Chica NAS, Key West, FL; Washington Air Route Traffic Control Center, Leesburg, VA; and two tours at the FAA Academy, Oklahoma City, OK.

Mr. Costilla's formal education includes M.S. Transportation Engineering, University of California, Berkeley, and a B.S. Industrial Physics from Central State University, Edmond, Oklahoma. His professional training includes over 2600 hours of FAA technical training and several hundred hours in FAA supervisor/manager courses. He holds a private pilot multiengine rating pilot's license.

Mr. Costilla is married and he and his wife have 5 children between the ages of 8-22.

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CHAPTER I

INTRODUCTION

It is estimated by 1995 there will be sufficient signals in space to permit global coverage with position determination information from such satellite-based systems as the United States Air Force (USAF) Global Positioning System (GPS), the Soviet Global Navigation Satellite System (GLONASS), and the European Space Agency NAVSAT. Primarily for military use, the GPS may serve civil aviation requirements as a sole means civil aviation radionavigation system once fully operational and approved for use by the FAA. Similarly, the Soviet GLONASS, considered a virtual replica of USAF's GPS, is expected to be fully compatible and interoperable. Europe is proposing that a refined version of the NAVSAT satellite-based navigation network be developed as a civilian system that initially would supplement services provided by GPS and GLONASS.

The potential GPS user set includes existing military and civil ground, sea, and air host vehicles, and space platforms, as well as new category users equipped with GPS receiver sets. As a result, it is

expected a worldwide user community will be affected by the availability and application of this technology. This study will focus on interoperability issues and implications associated with the use of domestic and/or foreign owned satellite-based navigation systems for civil air traffic control functions.

CHAPTER II

BACKGROUND

The United States Armed Services and several federal agencies, while in the interest of pursuing their respective missions, have been involved in space exploration since the 1960's. Specifically, the Air Force and Navy actively pursued the idea that navigation and positioning could be performed using radio frequency signals transmitted from space vehicles. In 1964-65 the FAA initiated an R & D program on feasibility of satellite communications for over-ocean use and, NASA was making history with its successful space exploration program leading to the lunar landing, a product of the Kennedy space program.

It could have been predicted that as the individual service programs naturally expanded in scope, overlapping and duplication of effort and areas of mutual interest would occur. As a result, the U.S. Deputy Secretary of Defense on April 17, 1974 designated the Air Force as the executive service to coalesce the concepts proposed for a Defense Navigation Satellite System into a unified DOD system. Thus, a system concept designated NAVSTAR Global Positioning System (GPS) emerged, combining the best features of

the previous navigation satellite concepts (i.e., Navy's TRANSIT and TIMATION and USAF's System 621B). The new system was to be developed by a Joint Program Office, managed by the U.S. Air Force Systems Command at Los Angeles Air Force Station.

The Department of Transportation (DOT) interests in satellite application activities were linked with DOD by the International Maritime Satellite Communications Act of 1978 which required the development of a plan to determine the most cost effective method of reducing proliferation and overlap of U.S. federally funded radionavigation systems. The resulting plan, the Federal Radionavigation Plan (FRP) first edition 1979, marked the first time that a Joint DOT/DOD plan for common-use systems (i.e., systems used by both the civil and military sectors) had been developed. Since the initial publication there has been significant changes in the radionavigation environment whereas GPS has been recognized as the principal driving force of the FRP.

Top level support and commitment for joint-use of GPS was given a boost shortly after the tragic downing of KAL-007, when President Reagan stated that

GPS services would be made available to world civil air transportation. (14:95)

Additionally, the U.S. has encouraged NATO participation in the development and deployment of GPS military user equipment. In response, ten NATO nations signed a Memorandum of Understanding in June, 1978 (updated in 1984) for participation in the development of GPS. These nations include Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, the United Kingdom, and the U.S. (12:22)

The objective of this agreement is to establish a flow of information among the participating nations regarding all GPS program activities to facilitate national decisions supporting the application and use of GPS.

Finally, worldwide interest in the development of comparable satellite-based global positioning systems has led to the US/USSR Transportation Agreement of 1988, wherein it states: (See Appendix 1)

"...the objectives of this mutual work is to improve the safety level and usefulness of transportation systems by jointly investigating the communications, navigation, and surveillance potential of satellite systems used by civil aviation. In that regard, consistent with international standardization activities, it is intended under the auspices of the Agreement to pursue a joint program designed to develop common standards for civil aviation use of the respective US-GPS and USSR-GLONASS systems."

CHAPTER III

SATELLITE-BASED RADIONAVIGATION SYSTEMS

Sparked by the potential utility and domestic and international markets, the United States and U.S.S.R. have been developing satellite-based position determination technology. This section will briefly describe NAVSTAR/GPS and the Soviet GLONASS.

Global satellite navigation systems have been under development by the United States and the Soviet Union since the 1970's and initially planned to become operational towards the end of the 1980's. The U.S. NAVSTAR saw its first launch in 1978 while the USSR GLONASS system was inaugurated 4 years later. Since then both systems have been developing towards an operational state now expected around 1991-92 following a variety of launch failures. Prior to May 1988, only NAVSTAR GPS was registered with international bodies such as the International Civil Aviation Organization (ICAO), and Inmarsat as a candidate for future navigation systems. In May 1988, at the ICAO meeting in Montreal, the USSR released details of the GLONASS system sufficient to provide the user with a position-fixing and timing capability comparable to GPS of 100 meters and 1 microsecond respectively. (1:13)

The release of technical data by the USSR to international bodies such as ICAO gives greater credibility to the prospects of a joint NAVSTAR GPS/GLONASS satellite navigation system being adopted for international use.

The following GPS information is taken in part from the Joint Program Office document YEE-82-009B GPS NAVSTAR USER'S OVERVIEW. (12:2)

GENERAL SYSTEM DESCRIPTION

The NAVSTAR GPS is a space-based radio positioning navigation and time transfer system that operates on two L-band frequencies: 1575.42 MHz (L1) and 1227.6 MHz (L2). The GPS comprises three major segments: Space, Control, and User.

1. The GPS Space Segment, when fully operational, will be composed of 24 satellites (includes three operational spares) in six orbital planes. The satellites will operate in circular 20,200-kilometer (10,900-nautical mile) orbits at an inclination angle of 55 degrees and with a 12-hour period. The precise spacing of satellites in orbit will be arranged such that a minimum of four satellites will be in view of any user, thereby ensuring worldwide coverage. Each satellite is designed to transmit an L₁ and L₂ signal. L₁ carries a precise (P) signal and a

coarse/acquisition (C/A) signal, while L_2 carries the P code only. Superimposed on these signals will be navigation and system data including satellite ephemeris, atmospheric propagation correction data, and satellite clock bias information.

2. The Control Segment includes a number of Monitor Stations and Ground Antennas located throughout the world. The Monitor Stations use a GPS receiver to passively track all satellites in view and thus accumulate ranging data from the satellite signals. The information from the Monitor Stations is processed at the Master Control Station (MCS) to determine satellite orbits and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the Ground Antennas.

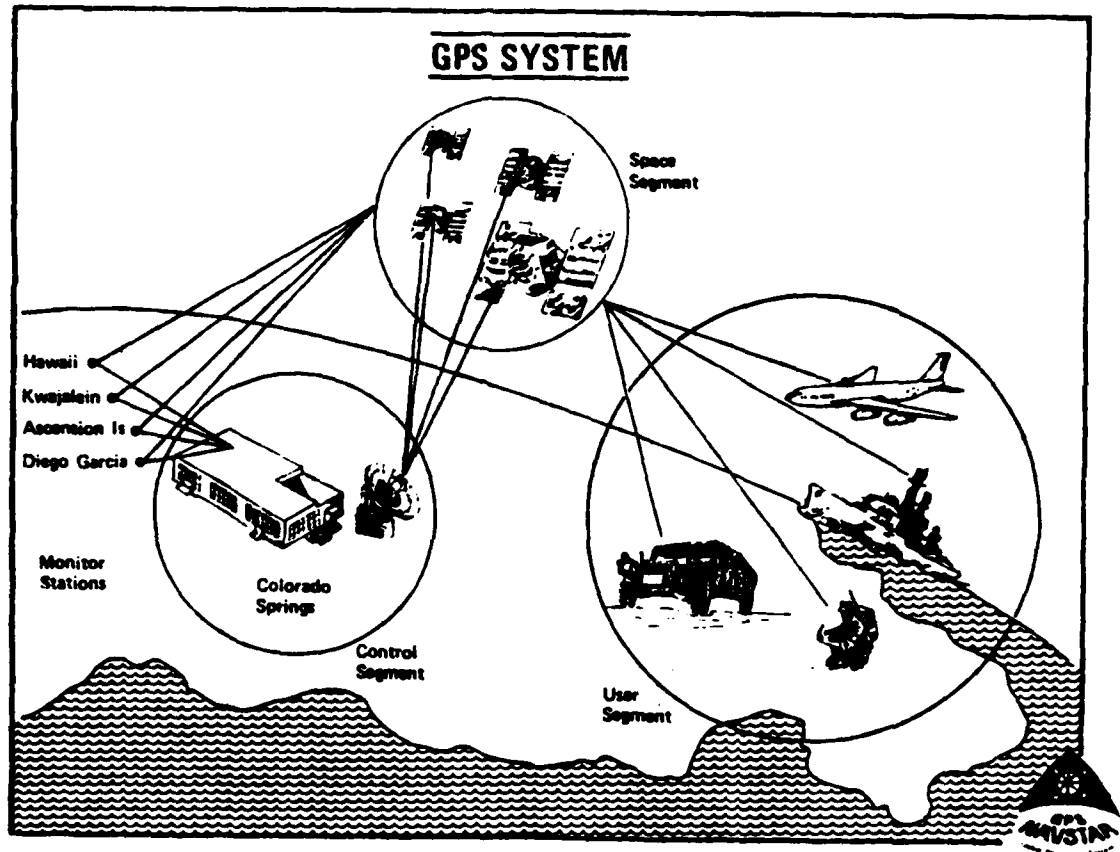
3. The User Segment consists of User Equipment (UE) Sets and associated support equipment. UE Sets, utilizing data transmitted by the satellites, derive navigation and time information for local use. The application of GPS UE in various types of host vehicles, used under a wide variety of operational conditions, has led to the development of three types of UE Sets--the Low Dynamic (one channel), Medium Dynamic (two-Channel), and High Dynamic (five-channel)

units. The five-channel Set continuously tracks and monitors four satellites simultaneously. The fifth channel is used to improve UE Set performance. The five-channel Set is normally used in a vehicle operating in a high dynamic and/or high jamming environment, or in a vehicle where fast acquisition of GPS signals is required.

Where operational conditions such as vehicle dynamics, operating time constraints, and jamming levels are less stringent, the one- or two-channel Set may be used. The one-channel Set tracks and monitors four satellites sequentially. In the two-channel Set, one channel sequentially tracks four satellites while the second channel performs background functions including the search for a rising satellite.

Four satellites are normally required for navigation purposes to establish a three-dimensional position determination and to estimate the user's clock error. Figure 1 depicts the GPS System.

Figure 1--GPS SYSTEM (12:3)



APPLICATIONS

Application of the GPS to various military and civil operations and specific missions provides many benefits to the user. GPS equipment will serve as a highly accurate positioning and navigation data reference. Knowledge of precise three-dimensional

position relative to friendly and enemy forces is fundamental to the success of a large number of military missions. Because GPS position is referenced to a common grid, the World Geodetic System 1984 (WGS-84), the civil and military position data can be standardized on a worldwide basis. The UE Set is capable of converting WGS-84 to other commonly used datums when operating with other map and data products. All of the applications identified herein benefit from the total GPS worldwide coverage, all-weather operation, and the unlimited number of passive users that the GPS can support. (12:8)

1. Military Applications--The substantial navigation performance improvements afforded by the GPS enhance many areas of military operations. In air operations, GPS accuracy can streamline en route and terminal navigation, thereby reducing flight times and fuel consumption. Since the GPS is a three-dimensional system, descent and non-precision approach and landing operations can be more closely controlled. In combat-related applications, GPS performance can improve coordinate bombing and ballistic weapon delivery. (12:8)

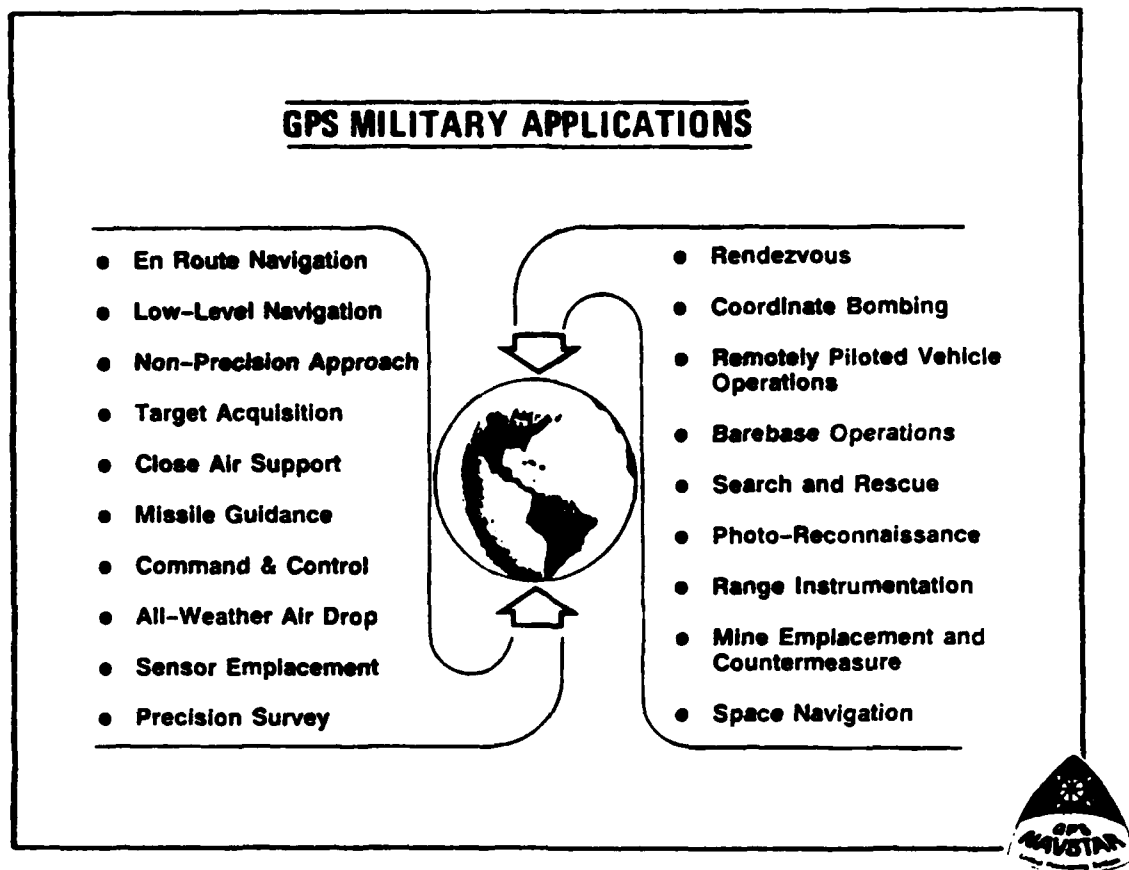
Since GPS allows the use of a common grid, all aspects of air, ground, sea, and space interoperability can be greatly improved. These interoperability aspects include close air support, rendezvous, multi-force command and control, pinpoint cargo drop operations, and search/rescue/evacuation operations.

For ground forces, the GPS can provide similar advantages. The precision position feature will enhance site surveying, field artillery placement, target acquisition and location, and target handoff operations. First-round artillery effectiveness can be improved based on precise knowledge of the location of friendly firepower, coupled with forward-observer determinations of enemy locations and movement. (12:8)

GPS can also provide benefits to naval forces. Harbor entry operations can be improved. Coastal survey operations can be conducted more quickly and effectively. Mine emplacement and countermeasure operations can be conducted with greater precision and safety. (12:8)

These are but a few of the military applications that will benefit from the GPS. Figure 2 summarizes the military applications.

Figure 2-GPS MILITARY APPLICATIONS (12:9)



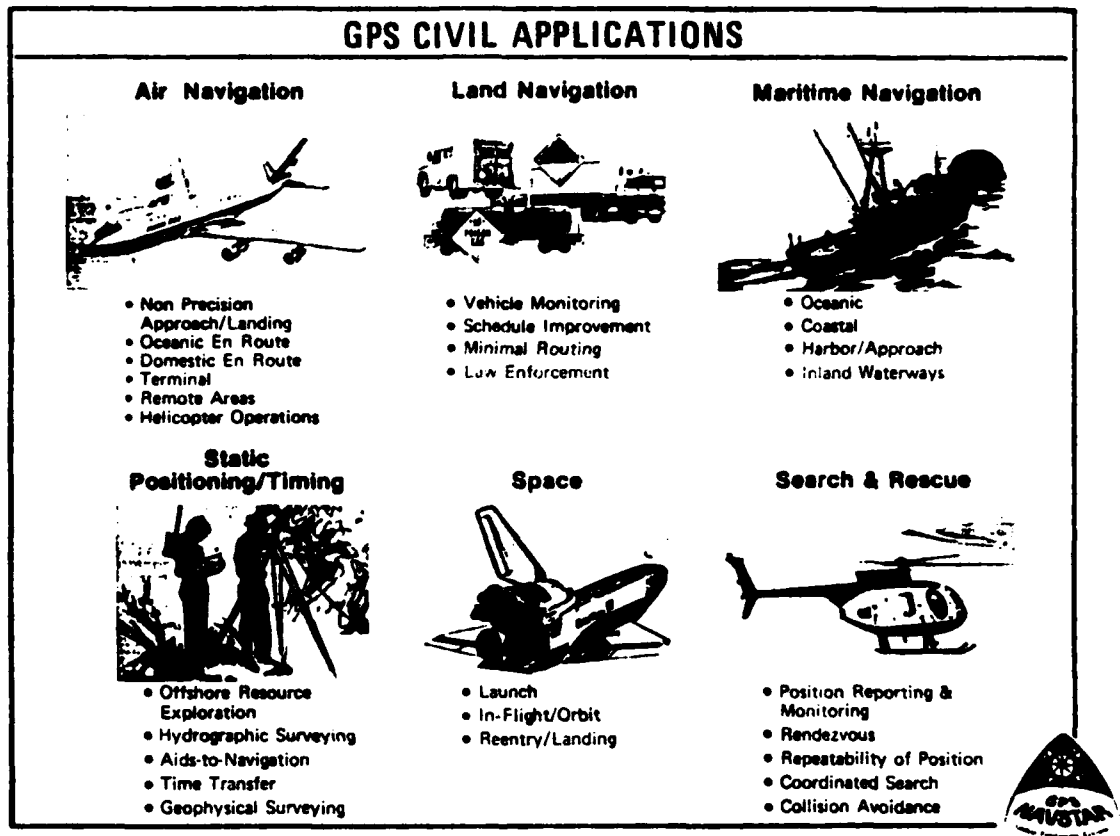
2. Civil Applications--The GPS will provide a broad spectrum of civil users with an accurate position, velocity, and time determination capability at a reasonable cost. (12:10)

In 1984, the Department of Defense authorized an increase in position accuracy derivable from NAVSTAR GPS signals for the civil community. Civil users will be able to determine position to within 100 meters once the 24 satellite constellation is operational. The Department of Defense has also established a policy on

the civil use of the Precise Positioning Service (PPS). This policy states requirements that must be met to allow for limited civil access to full GPS accuracies. The requirements specify that the granting of access may be allowed if: it is in the national interest of the United States; equivalent accuracy cannot be achieved by other means; and the security concerns of the GPS are adequately provided for.

Search-and-rescue techniques can be enhanced through use of the precise position identification capability of the GPS. The mineral exploration and geophysical survey communities will be able to accurately locate ore bodies, potential petroleum bearing areas, and active fault belts in a shorter period of time. The GPS common grid feature will also enhance many land-vehicle operations. Figure 3 highlights GPS civil applications. (12:10)

Figure 3-GPS CIVIL APPLICATIONS (12:10)



The potential applications for GPS are boundless. As the system gains acceptance by the civil community, more sophisticated uses for this system will be established. That is why the developers of the GPS consider it the positioning and navigation system for both today and tomorrow.

GLONASS

The Soviet Global Navigational Satellite System (GLONASS) is designed to be a virtual replica of the U.S.'s new NAVSTAR Global Positioning System. Not only will GLONASS employ the same basic orbits as GPS, i.e.,

circular semisynchronous orbits, but GLONASS will also operate in frequency bands very close to GPS: 1250 and 1603.5 MHz center frequencies for GLONASS versus 1227.6 and 1575.4 MHz for GPS. (10:48)

Although GLONASS policy and technical data has not been released by the Soviets until recently, available information suggests the GLONASS system will indeed be comparable in system configuration and performance to the GPS. For example, the International Maritime Organization, Sub-committee on Safety of Navigation, 35th session, 9/27/88, included the following GLONASS information submitted by the U.S.S.R.: (6:ANNEX)

"The GLONASS system is designed for position and velocity determination of the civil marine and fishery fleet and also civil aircraft. The GLONASS satellites are distributed over 19,100 km high near-circular 11 hr 15 min orbits with a 64.8° inclination. Initially the system is planned to consist of 10 to 12 satellites with 5 to 6 in two orbit planes the descending nodes of which are spaced 240° apart making at least 4 satellites visible during a 10-18 hr period daily. In the fully operational configuration (a 24 satellite constellation including 3 spares) the satellites are spaced in three orbit planes with 7-8 in each of the orbit planes. The orbit planes are equally (120° apart) distributed in the equator plane." (2:ANNEX)

The information given by the Soviets goes on to say the initial system (10-12 satellites) will be operational by 1989-90 while the fully operational configuration is expected by 1991-95.

Additional technical information regarding GLONASS performance is provided by the University of Leeds, Dept. of Electrical and Electronic Engineering, UK, 7/88, as a result of their independent testing of present generation pre-operational GLONASS and GPS satellites:

"Details of the USSR's global satellite navigation system GLONASS currently available allow the system to be used to carry out position-fixing and timing measurements. The results can be compared with those achievable with NAVSTAR GPS and conclusion drawn as to the possibility of employing a common navigation system...The results encourage us to propose a range of experiments in the future at several laboratories aimed at evaluating the two systems and eventual integration." (1:13)

The article further concludes:

"The figures presented lead one to conclude that GLONASS is capable, when operated with C/A code phase (a civil-use code signal) in the same manner as NAVSTAR GPS, of the same level of performance. In terms of position fixing, we observe a position fixing capability using code phase only and signal averaging well within the quoted accuracy of 100 m, probably of the order of 10-30 m." (1:18)

The University, however, was quick to disclaim the results as pertaining to pre-operational satellites only which may differ once the operational system is deployed.

CHAPTER IV

AIR TRAFFIC CONTROL (ATC) APPLICATIONS

Space-based technology has tremendous potential to supplement and improve the present land-based navigation system in the United States and ultimately, replace it with a space-based world-wide sole means navigation system of the future. This chapter will briefly describe the implications of GPS on the present generation ATC system and discuss future considerations and applications of satellites in the development of a spaced-based ATC system of the future.

GPS is being evaluated to determine its role in the present aviation radionavigation system "mix" in the U.S. These systems are sometimes used independently or in combination by the user depending on flight requirements. The Federal Radionavigation Plan (FRP) lists the existing navigational aids or nav aids as follows: LORAN-C, OMEGA, VOR, VORTAC, VOR/DME, TACAN, ILS, TRANSIT, Radiobeacons, and MLS. (3:x111)

For aviation purposes, each of these systems satisfy specific phase-of-flight requirements, e.g., VOR for en route/terminal phase and ILS for the approach/landing phase. Presently, GPS is planned for the en route/terminal and non-precision approach phases

of flight. It is not intended to be used as a precision landing aid at the present time. (3:1-7)

The FRP contains the following objectives regarding GPS implementation:

"It is the goal of DOD to phase out military use of TACAN, VOR/DME, OMEGA, LORAN-C, and ILS and to discontinue operation of TRANSIT. A decision to discontinue Federal operation of VOR/DME, OMEGA, or LORAN-C by DOT will depend upon (a) resolution of GPS accuracy, coverage, integrity, and financial issues; (b) determination that GPS meets civil air, marine, and land needs currently met by existing systems; (c) development of GPS civil user equipment prices that would be economically acceptable; (d) establishment of a transition period of 15 years; and (e) resolution of international commitments." (3:1-6)

The Air Traffic Control System is that combination of controllers, procedures, automation and computers, interfacility communications, and flow management needed to provide the service. The radionavigation aids referenced above are part of the support systems necessary to facilitate ATC service to the user. The other ATC support components are radar surveillance and communications referred in this paper as CNS services (communications, navigation, and surveillance). The ATC system of the future depends on CNS services provided by satellite-based technology.

The present mix of radionavigation facilities in the National Airspace System (NAS) have operational limitations and inherent system deficiencies. They are identified by the Radio Technical Commission for Aeronautics (RTCA), Special Committee 155: (see Appendix 2:2)

- lack of sufficient airport and heliport facilities in major city areas,

- lack of surveillance information in much of the airspace over oceans and unpopulated areas,

- lack of instrument approach capability to many paved and lighted airports, and perhaps most important,

- lack of low-altitude communication, navigation, and surveillance (CNS) coverage in most areas of the world.

FAA's Acting Deputy Associate Administrator for NAS Programs, Mr. Martin T. Pozesky, sums up the prevailing consensus to the existing system deficiencies in his statements to the AUSRIRE Technical Symposium, Leningrad, U.S.S.R., May 25-29, 1987. (See Appendix 2:2)

"The growing view is that the most effective way to reduce or eliminate some of the these system deficiencies is through the use of satellites as a way of gathering information and improving the information flow, which is the key to aviation system improvement."

GPS, once operational and certified for civil use, can provide immediate improvements as a supplemental system to the existing ATC radionavigational aids. For example, GPS will provide navigation service to properly equipped users in those areas not presently covered by land-based equipment or where the signals are not useable due to weather, line-of-sight, or other limiting factors. Indeed, with its unlimited coverage capability, GPS has the potential to replace selected navigational facilities by providing continuous navigation information thereby representing a significant savings in maintenance and operations costs. Operationally, users should begin to benefit from GPS in oceanic flights and low/no coverage areas.

Present ATC flight rules are predicated on the existing NAS radionavigation mix and system architecture. For example, airways exist only in areas with adequate navigation coverage. However, with GPS, and its unlimited coverage capability, perhaps airways could be eliminated thereby allowing users unrestricted passage to choose the most efficient and cost-effective routes.

As can be seen, ATC rules will require changes to accomodate technological improvements. Indeed, it is predicted the ATC system of the future will develop and employ new concepts and principles based on advancements brought about by satellite technology. Referring once again to Mr. Pozesky, he stated the following regarding future satellite applications in ATC:

"...FAA last year developed its vision- its snapshot in time- of the future communications, navigations, and surveillance (CNS) system. This vision of the future represents the broad views of FAA and reflects the work done by the RTCA Special Committee 155 activity. We offered this view to the ICAO Future Air Navigation System (FANS) Committee at FANS-3 last November, and were pleased that there is a remarkable coherence of views among the members of the FANS Committee. An important contribution was made at FANS-3 by the USSR in FANS Working Paper 90, "Conception and Stages in the Construction of a Global Satellite-Based System for Communications, Navigation, and Surveillance." (Appendix 2:5)

As a result, ICAO has outlined the world's next air navigation system. The ICAO FANS Committee is looking at the next 25 years to make recommendations on the entire realm of CNS. The following are highlights from their work as contained in the October 1988 issue of AVIONICS: (16:8-12)

1. From its study of new concepts, the committee has concluded that satellite technology on a global basis

is the only solution to shortcomings of the present system:

- Line-of-sight limitations and variability of radar propagation;

- Difficulty in operating present CNS in large parts of the world; and

- Limits of voice communications and lack of digital air-ground interchange to support automation in the air or on the ground.

2. New CNS systems, therefore, should provide:

- Global communications, navigations and surveillance from low to high altitude, and cover remote, off-shore and oceanic areas;

- Digital data interchange between air and ground to exploit automated capabilities of both; and

- Navigation/approach service for runways which do not meet precision landing aids (MLS).

- Improved transfer of information between aircraft and ATS (Air Traffic Service).

- Surveillance, especially over water, by deriving aircraft position from airborne avionics (automatic dependent surveillance, or ADS);

- Ground-based data processing, including display of ADS-derived data ("pseudo-radar display"), allowing for:

- improved navigation accuracy in four dimensions (i.e., position, altitude and time);
- additional flight paths, based on operator objectives; and
- improved conflict detection, automated generation of conflict-free clearances and rapid response to changing traffic conditions.

In summary, developments in technology appear to justify the prediction that global navigation satellite systems that provide "independent" on-board position determination, will evolve as sole means of navigation, and eventually replace current navigation aids. The following sections describe GPS applications and implications on CNS, avionics, and ground based ATC control facilities.

CNS

This section describes CNS enhancements as taken from the FAA speech given at the AUSRIRE Technical Symposium, Leningrad: (Appendix 2:6-7)

1. Communications: The bulk of ATC communications will use digital data link techniques to permit high efficiency in information flow. Data link communications are an essential ingredient in ATC automation. A limited voice capability will be required for en route areas; more voice communications

is likely to be needed in terminal areas. A satellite communications relay will be used extensively to provide automatic dependent surveillance (ADS) position information. Communications services (data and some voice) between aircraft and the ground system will use satellite relay in over-ocean and remote land areas, at low altitudes in both low-density and high-density en route areas, and for other purposes. In high-density terminal areas, terrestrial direct air-ground communications will be preferable to a satellite-based communications system.

2. Navigation: Navigation is likely to be based largely on a high-integrity and high-accuracy global satellite-based navigation system. Three-dimensional information will be available, along with a standard system time service. This system will provide at least "nonprecision approach" capability everywhere. Flexible precision approach and landing, and precision missed approach service will be provided by the Microwave Landing System. Air traffic management, where practical, will be based on a minimum required navigation performance (RNPC) capability. Barometric altitude will remain the system standard in most airspace, but geocentric altitude available from the satellite navigation system could serve as a crosscheck

on vertical position in the lower portions of the airspace.

3. ATC Surveillance: There is broad agreement that aircraft navigation systems, along with automatic altitude-reporting capability, will be of sufficient integrity to serve as the source for automatic dependent surveillance (ADS) using the concept and approach already agreed by ICAO FANS. Initially, the navigation systems currently in wide use, dominantly inertial navigation systems over the oceans, will provide an excellent surveillance service--far superior to the current voice reports of aircraft position.

AVIONICS

In order to maximize and fully exploit projected GPS/CNS enhancements, it is only logical that "cockpit" technology be developed to maintain equal pace. GPS based avionics integrated with other aircraft information and guidance systems will determine the scope of operations, provide real-time aviation system information, and will most certainly provide a new dimension to flight safety. For example, a fundamental design principle (ADS, described earlier) is that all vehicles will participate in the future ATC system by automatically determining their position and transmitting that position (via GPS/data

receiver/transmitter technology), information to ATC and other discreet system users.

In the stand-alone configuration, the GPS/SPS avionics receiver will provide the pilot with basic navigation data. Other applications however, include GPS interface options such as GPS-INS to improve on-board navigation accuracy and capability. And, GPS-collision avoidance avionics will provide the pilot with real-time independent surveillance of surrounding air traffic and indeed, with sufficient automation capabilities, could identify possible conflicts while providing the pilot with evasive and/or clearance information.

FAA is the lead agency to develop the minimum performance requirements for GPS based avionics to be used in the National Airspace System and integrate their use. To assist in this effort FAA is working with DOD, private industry, and several technical groups such as RCTA and IEEE. Additionally, the FAA is working with ICAO to develop similar standards applicable to international aviation. There are presently 54 companies developing/manufacturing GPS receivers as listed in USAF's document, Introduction to NAVSTAR GPS User Equipment, by the GPS JPO.

(14:15-1-15-14)

DOD and DOT are working together as mentioned previously, to ensure GPS avionics development is mutually compatible and duplication of effort can be minimized. FRP R,E & D goals include GPS receiver development in the following GPS system goals: (3:4-3)

- DOD will evaluate the costs of all radionavigation systems, including GPS and MLS, which meet civil user requirements.

- DOT will provide DOD with the most current information on civil user requirements which may have a significant impact on DOD-operated radionavigation systems.

- Consistent with existing DOD policy, DOD will provide information to DOT on GPS receiver designs that may be applicable to low-cost civil receiver development.

- DOT will conduct studies of GPS performance capabilities of low-cost receivers in order to provide an assessment of their applicability to the civil sector.

GROUND-BASED ATC FACILITIES

Given the projected evolution of satellite CNS services and the development of corresponding advanced avionics, there remains the task of developing the ground-based facilities necessary to facilitate, coordinate, and manage the ATC system of the future. Although DOD is responsible for the maintenance and operation of GPS, the FAA is responsible for the maintenance and operation of all existing ground-based ATC facilities comprising the NAS, e.g., display and processing equipment, communications/radar transceivers and other information and control equipment. Much of the R, E & D effort in this area is being done at the FAA Technical Center in Atlantic City, N.J.

With expanded CNS services, FAA is evaluating several ATC ground-based monitor and control facility configurations similar to DOD's thereby, reducing the number of existing facilities by expanding the area of control.

In addition, GPS and other satellite technology enhancements affecting the ATC system will require changes in such areas as; controller training, changes in flight rules and procedures, and logistics.

Due to the joint-use and international implications of a global navigation system, GPS/ATC interoperability issues must be resolved prior to integration into the NAS. Some of these issues are discussed in the following chapters.

CHAPTER V

INTEROPERABILITY ISSUES

This chapter will focus on key interoperability issues related to; (1) GPS service when applied to civil air navigation as described in the previous chapter while maintaining its primary military mission integrity and; (2) combined use of GPS and GLONASS to provide a world-wide navigation system.

JOINT-USE GPS

As previously mentioned, GPS technology is the principal driving force of the Joint DOD/DOT Federal Radionavigation Plan (FRP), which proposes to replace present generation navigation and landing aids with GPS and indeed, become this nation's sole-means air navigation system of the future. (3:1-6)

DOT's Federal Aviation Administration (FAA) has responsibility for development and implementation of radio-navigation systems to meet the domestic needs of all civil and military aviation. The FAA also has the responsibility to operate aids to air navigation required by international treaties. As such, FAA has responsibility for the evaluation and integration of GPS into the National Airspace System of the future.

Air navigation requirements and GPS evaluation and testing data are updated and documented in the current FRP.

A brief description of GPS was provided earlier wherein it was described to be comprised of the space segment, the control segment, and the user segment. Since GPS is DOD owned and operated, FAA's primary mission is to develop the user requirements and standards, test, evaluate, and integrate GPS related hardware and software into this nation's National Airspace System (NAS).

FAA has been involved with the GPS program from the start representing user interests and requirements. During the early days of the program it was determined that if GPS was going to be used in the NAS, then it should be as good as or better than what is now providing aviation navigation.

As with any new navigation system being considered for public use, the FAA is obliged to evaluate GPS to ensure it meets certain technical and operational performance requirements. For GPS, they include the following ten performance characteristics:
(3:A-2)

- | | |
|--------------------------|-------------------|
| • Signal characteristics | • Accuracy |
| • Availability | • Coverage |
| • Reliability | • Fix rate |
| • Fix dimensions | • System capacity |
| • Ambiguity | • Integrity |

The following table shows the characteristics of GPS currently under development when evaluated against the system performance parameters described above. Note: Results based on 21 satellite constellation. The availability, coverage, and reliability parameters are expected to approach 100% when evaluated against the 24 satellite constellation recently approved by DOD.

TABLE FRP (3:A-6)

SYSTEM Global Positioning System (GPS)

SYSTEM DESCRIPTION: GPS is a space based radio positioning navigation system that will provide three dimensional position, velocity and time information to suitably equipped users anywhere on or near the surface of the earth. The space segment will consist of 18 satellites plus 3 operational spares in 12 hour orbits. Each satellite will transmit navigation data and time signals at 1575.4 and 1227.6 MHz.

ACCURACY			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
PPS* Horiz - 17.8m Vert - 27.7m Time - 90 ns	Horiz - 17.8m Vert - 27.7m	Horiz - 7.6m Vert - 11.7m	Expected to approach 100%	Worldwide continuous	98% probability that an 18-satellite constellation will be available	Essentially continuous	3D + Velocity + Time	Unlimited	None
SPS Horiz - 100m Vert - 156m Time - 175ns	Horiz - 100m Vert - 156m	Horiz - 28.4m Vert - 44.5m							

* For US and Allied military, US Government, and selected civil users specifically approved by the US Government.

RESULTS

FAA's basic R, E & D activities for GPS have been generally completed with coverage reliability and integrity being the only remaining issues to be resolved. These activities have included substantial efforts to evaluate technical, operational and economic characteristics. The evaluation process has included simulations, engineering models, user equipment design and flight tests. Note: Since the FRP report of 1986, the coverage reliability issue has been resolved with the increase in the operational satellite constellation.

GPS INTEGRITY ISSUE

The current GPS satellite and control segment failure warning system does not provide warnings soon enough after an out-of-tolerance condition occurs to be suitable for civil air navigation purposes.

The FRP describes the integrity issue as follows:

"In accordance with the DOD GPS concept, GPS satellites are monitored more than 95% of the time by a network of five monitoring stations spread around the world. The information collected by the monitoring stations is processed by the Master Control Station at Colorado Springs, CO, and used to periodically update the navigation message (including a health message) transmitted by each satellite. The satellite health message, which is not changed between satellite navigation message updates, is transmitted as part of the GPS navigation for reception by both PPS and SPS users. Additionally, satellite operating parameters such as navigation data errors, signal

availability/anti-spoof failures, and certain types of satellite clock failures are monitored internally within the satellite. If such internal failures are detected, users are notified within 6 seconds. Other failures detectable only by the control segment may take from 15 minutes to several hours to rectify." (3:A-34)

FAA views the integrity characteristic as unacceptable for civil use as a sole means navigation system. All other technical performance characteristics are adequate to meet civil air navigation requirements.

The current practice in aviation for navigation is to have an external monitor for each signal source and when the monitor detects the signal is out-of-tolerance, the source is turned off within a limited time thus, inhibiting the signal from the users. For example, the VORTAC shuts down in 6 seconds or less when an out-of-tolerance condition is detected. GPS, as it is now planned to be implemented does not have this capability. Although self checks in the satellites detect certain major malfunctions which when detected make the signal unusable, GPS relies on the Control Segment to detect and report or correct minor out-of-tolerance conditions. This process can take up to 20 minutes or more before the situation is corrected

or the user notified. This is not acceptable for aviation safety.

ALTERNATIVES

Integrity work in the FAA has been on providing suitable integrity for nonprecision approaches and the criteria most often used is that the pilot must be notified within 15 seconds from the time the system accuracy performance is beyond 100 m. This is not an easy criteria to meet. Part of the problem is determining when the system performance is outside-of-tolerance. Position determination is dependent on the pseudo range from at least 4 satellites and the geometry of the user and the satellites. This implies that the best method for achieving suitable integrity would be for the user equipment to measure the system performance. Work done to date has shown that if there are at least 5 satellites in view with good geometry and if only one of the satellites is out-of-tolerance and the geometry is such that it causes a position error then the user equipment can detect there is an error. However, it takes one good satellite with good geometry to isolate the bad satellite pseudo range and allow the navigation function to be used. While the 21-operational

satellites with 3 operational-on-orbit spares (24 satellite) constellation provides adequate redundancy for worldwide coverage, it is not suitable for nonprecision approach integrity. (Appendix 3:7)

The USAF GPS JPO, as stated in their NATO Team User Equipment document, recognize the integrity issue as an FAA requirement and state their views as described below.

1. To have a minimum of 5 satellites in view at all times requires an increase in the number of satellites in the constellation from 21 to 24. (14:13-3) This has been approved by DOD in March 1988. See Appendix 2 for related message.
2. To provide for no more than 10 seconds delay of warning to aircrew that a satellite in use is passing poor/bad information, JPO states:

"If GPS receivers relied on the satellite health information in the NAV-msg to relay failure information, the delay could be hours long under certain circumstances. Alternative solutions have been proposed and they can generally be divided into two categories: internal and external warning systems." (14:13-3)

-The internal warning systems use GPS/INS or receivers that check any combination of 4 satellites of those satellites visible to determine which satellite transmits bad information. This combination technique together with the redundancy problem are the main

reasons for FAA requirement of at least 5 satellites in view at any one time. (14:13-3)

-The external systems will use independent reference stations on the ground that check the signal quality of all satellites in view via ground-based radiobeacons or geostationary satellites. (14:13-3)

DOD has chosen the internal system integrity check for military purposes as taken from the FRP:

"The DOD user equipment utilizes the information obtained in the navigation and health messages, as well as self-contained satellite geometry algorithms and internal navigational convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information."
(3:A-34)

OTHER DOT CONCERNS

By and large, the vast number of interactive and/or interdependent matters concerning joint use of GPS are being resolved prior to their becoming issues by the cooperation, participation, and deliberation between DOD and its user partners, i.e., DOT and other agencies and NATO.

The FRP identifies DOT interests and concerns regarding the selection and use of GPS in the NAS. They are listed below for information purposes however, are not considered interoperability issues at this time.

-Survivability: interruption or degradation of system operation by enemy attack, political action, or natural causes.

-Civil/Military Compatibility: DOD aircraft and ships operate in, and must be compatible with, civil environments. Thus, there are potential cost advantages in the development of common civil/military systems.

-Review and Validation: determination of impact of new military requirements on the civil sector.

-Economic considerations: direct cost to the government, as the provider and operator of radionavigational services, and to the user, who must buy the equipment needed to use the services, must be carefully analyzed. In the civil sector, the cost of new user equipment such as GPS receiver options, influences the acceptability of a new system by the majority of civil users. Therefore, the internal system solution to the integrity issue described above is prohibitive to the civil sector due to the increased cost to the user by driving avionics requirements up.
(3:1-20)

-Institutional considerations: the principal institutional consideration is the formulation of a strategy for the radionavigation systems selection include the following:

1. Cost recovery for radionavigation services--DOT has proposed the implementation of fees to affect all user groups i.e., air, land, and marine, commensurate with the benefits received by each user group. FAA presently recovers service costs from the civil aviation community by imposing system user taxes on such as; passenger ticket tax, aviation fuel tax, tube and tire tax, etc. (3:1-21)
2. Signal availability in time of National Emergency--the U.S. national policy is that all radionavigation signals (LORAN-C, OMEGA, VOR/DME, GPS, TRANSIT, etc) will be available at all times except during a dire national emergency when only those radionavigation signals serving national interests will be available. (3:1-21)
3. International acceptance of navigational systems: the goals of standardization and cost minimization of user equipment influence the search for an international consensus on a selection of radionavigation systems. FAA in consultation with DOD, is responsible to promote the GPS minimum operating performance standards for the domestic and international civil user segments. (3:1-22) This is being done through ICAO and directly with the USSR.

4. Role of the private sector: since the role of the private sector to provide commercial satellite-based services is increasing, e.g., radiolocation service, television, communications, etc., can or should radionavigation service be commercialized?

5. Criteria for selection (as a national joint-use navigation system): at a minimum, future systems like GPS should meet joint DOD/DOT selection criteria in such areas as service, visibility, standardization, and costs. (3:1-22)

GPS/GLONASS ISSUES

As mentioned in the opening statement of this paper, that by 1995 there will be sufficient signals in space to permit global coverage with position determination information from such satellite-based systems as GPS and GLONASS (and NAVSAT). This implies, given adequate service, the radionavigation source is "transparent" to the user. Furthermore, with the integrity issue pending resolution whereby GLONASS could increase the number of usable satellites in view, and other third world interests, the combined use of GPS and GLONASS to satisfy the radionavigation needs of the future, is growing in interest. Indeed, much of the effort to standardize

the service to date has been in the interest of gaining international acceptance. This section will highlight key interoperability issues identified thus far which must be resolved if such a system could be considered in the future NAS radionavigation mix and indeed, as an international navigation system. The reader is reminded that limited data exists regarding GLONASS. US/USSR discussions have just begun to collect this information, compare, validate, and resolve any differences.

Although there exists certain limited first-hand technical and performance data in the public forum regarding the GLONASS system, already several compatibility issues and concerns are being identified by DOT/FAA requiring validation and resolution.

TECHNICAL CONSIDERATIONS

For this discussion, reference will be made to the technical performance characteristics applicable to GPS and only those with sufficient information and potential conflict with GPS will be addressed. Thus far, in this area there appears to be four major differences between the two systems: (1) satellite identity, (2) message format/code rate, (3) world map reference datum, and (4) time reference system. The following information

is taken from University of Leeds, "Position-Fixing Using the USSR's GLONASS C/A Code", published by IEEE, CH 2675-7/88/0000-0013, 1988. ((1:13-19)

1. Satellite identity--from the data submitted by the USSR and reported by the University of Leeds, each GLONASS satellite is assigned a discreet transmission frequency which serves to identify it from other satellites in view. In contrast to GPS where the transmitted code contains the satellite ID.
2. Message format/code rate--the GLONASS low precision code (equivalent to GPS/SPS) has 511 intelligence bits as compared to NAVSTAR's 1023 bits for its equivalent code. The GLONASS code rates are 511 k bits/sec compared to 1023 k bits/sec for GPS.
3. Earth reference datum--tests indicate that GLONASS utilizes an on-board coordinate reference system (to calculate and transmit its satellite ephemeris data) different than the WG-84 ellipsoid employed by NAVSTAR GPS as described in Chapter 3 of this study.
4. Time coordinate reference systems--the time transmitted to the user by the navigation satellite is extremely important to calculate accurate position determination information. The GLONASS system is weak

In providing precise and consistent time information. GLONASS timing analysis conducted thus far cannot link the received system timing data to the common UTC (Universal Coordinated Time) used by GPS for master timing.

The above are the key GPS/GLONASS interoperability issues to be addressed thus far. As more data becomes available, GLONASS will continue to be subjected to the same evaluation process as GPS to determine its capabilities to augment and/or share the GPS navigation responsibilities of the future. It is anticipated the GLONASS system will face the same operational, economic, and institutional considerations as GPS, i.e., system integrity, user fees, avionics costs, and overall system use. Obviously, it would be in the best interest of the aviation community to achieve maximum compatibility so as to obtain maximum benefits to the users.

CHAPTER VI

FINDINGS AND CONCLUSIONS

Based on all available information the USAF NAVSTAR GPS Program is alive and well. It is anticipated the full 24 satellite constellation will be "on-orbit" by the end of 1992 as planned and operational shortly thereafter. From the military perspective, the GPS navigation system is recognized as a critical player in its continuing efforts to achieve enhanced mission capabilities in the future. The GPS, perceived by many as revolutionizing present navigation methods, has been given major status and priority in terms of funding and launching within DOD. Indeed, this is a system with international implications adding increased impetus and pressures to achieve operational status on schedule. In fact, it can be concluded that although GPS is significant to the civil sector, it is my opinion the major pressures being brought to bear on the GPS program are from DOD sources.

This study was made not to confirm GPS as a major military asset of the future but to determine its impact on civil air navigation. Some of the major issues associated with its implementation both in the

domestic and international sense were evaluated. There were some basic questions going into this study regarding the GPS program and, ironically, just as many questions were raised as a result of it which remain to be resolved. Indeed, from a programmatic and national-use perspective, this represents new challenges to DOD and DOT never before faced. This study makes several points below regarding its findings and conclusions.

1. GPS requires executive level support to ensure dual role mission, i.e., civil and military integrity, is maintained. Due to the downing of KAL-007, national attention was focused on this issue serving to emphasize the importance of GPS to civil aviation. It is anticipated DOD and DOT will continue to compete for limited resources in the future to satisfy their respective requirements mainly through the satellite replenishment program by requiring more "bells and whistles." Although DOD and DOT are interdependent in civil air navigation because DOD aircraft are required to fly under civil control while operating in public airspace, future changes to the satellites by special interests will impact the other users. Indeed, how will changing DOD space policy from

one of peace initiatives to a warfighting theme affect the civil programs? These type issues affecting a national asset such a GPS will require the highest level of authority commensurate with its value towards achieving national security objectives and to ensure it continues to serve U.S. peacetime and wartime requirements.

2. The sustainability issues requires further study to identify alternatives. Very little information is available regarding the sustainability plan of the full 24 satellite constellation once operational. Such factors as future launch capabilities, funding, and program requirements are subject to change. These areas should be analyzed to identify alternatives to insure uninterrupted service is provided to all present and future users.

3. I feel the joint-use policy adopted by the U.S. in the use of GPS for domestic and military purposes represents a significant challenge and milestone in the nation's modernization efforts. First, for DOT/FAA, it is the first major national system for which it will not have full control and responsibility. Therefore, it must develop the confidence and trust in the system to integrate it into the NAS and in DOD/USAF to provide continual service and response. For the military, the

civil requirements must be considered in all aspects of its future R,E & D and implementation program unlike other military systems. This approach is a milestone because as GPS is being considered by the FAA to provide the future navigation functions of ATC, it is also looking towards satellite technology to provide future communications and surveillance services which may also be military owned and operated. I think this approach is necessary in terms of costs, i.e., satellite production and launch costs; however, the discreet requirements and missions are sufficiently different in terms of scope and priority that operational conflicts are inevitable. How these are handled and resolved remains to be seen over the next few years.

4. The FAA Integration plan for the use of GPS in civil air navigation must be developed and implemented at the earliest opportunity. There appears to be some conflict with the on-going National Airspace System Plan to modernize the present ATC system over the next 10 years with state-of-the-art terrestrial-based technology and the introduction of satellite-based technology. The readings indicate the FAA views GPS

with long-term (post NAS Plan) applications whereas in contrast, the USAF is already procuring GPS receivers and planning to replace military use nav aids. It is my opinion the FAA should re-evaluate its modernization plans in light of GPS service availability and cost/benefit considerations.

5. GPS system integrity is a major issue for the FAA. The internal and external warning systems were discussed; however, it appears any resolution will require considerable investments to the user or provider. From the FAA point of view, one of its primary objectives is to maintain or reduce the cost of GPS-based avionics as compared to present generation avionics so as to promote the transition to GPS. The military solution to include the integrity check capability in their receivers raises the cost to the users when applied to the civil sector. Thus, the FAA is evaluating the feasibility of incorporating ground-based integrity checks with quick response and notification to affected users. In my opinion, this would be the preferred alternative; however, it must be approved and recognized by the USAF since they would be responsible for taking corrective action once notified.

study, the US/USSR Transportation Agreement provides for the continued cooperation by the U.S. FAA delegation to promote GPS standards throughout the world. I feel, due to the avionics cost considerations, GLONASS compatibility will be of interest primarily to the international user.

In conclusion, I wish to point out the significance of this program as a true joint-use effort with national and international implications. It represents the ability to revolutionize the navigation industry bringing the world closer together by expanding its services to all parts of the world. Considering the importance of GPS to the military mission, one comes to realize the equal importance of GPS to the civil sector and to the national security of this country.

Appendix 1

**US Federal Aviation Administration (FAA)/USSR
Ministry of Civil Aviation (MCA) GPS-GLONASS
Cooperation Conducted Under the Auspices of
The US/USSR Transportation Agreement**

US FEDERAL AVIATION ADMINISTRATION (FAA)/USSR
MINISTRY OF CIVIL AVIATION (MCA) GPS-GLONASS
COOPERATION CONDUCTED UNDER THE AUSPICES OF
THE US/USSR TRANSPORTATION AGREEMENT

PURPOSE: In May 1988, an agreement was signed at the summit meeting for cooperation in the field of transportation systems. Within the civil aviation section of the Agreement, it was indicated that cooperation would proceed in the use of satellites for civil aviation applications. As stated in the Agreement, the objective of this mutual work is to improve the safety level and usefulness of transportation systems by jointly investigating the communications, navigation, and surveillance potential of satellite systems used by civil aviation. In that regard, consistent with international standardization activities, it is intended under the auspices of the Agreement to pursue a joint program designed to develop common standards for civil aviation use of the respective US-GPS and USSR-GLONASS systems.

BENEFITS: At a recent meeting of the Future Air Navigation Systems (FANS) Committee of the International Civil Aviation Organization (ICAO) it was recognized and recorded that "satellite-based communications, navigation, and surveillance systems will be the key for worldwide improvements" for civil aviation. In that regard, FANS indicated that ~~compatibility~~ *Computability* between such satellite systems would be of great benefit in terms of civil integrity, coverage, accuracy, and redundancy. This compatibility would practically insure that regional or global interruptions or failures of a single system would threaten neither the safety nor the reliability of civil aviation.

In the area of navigation, the emerging US Global Positioning System (GPS) has been cited as a candidate for providing services to civil aviation and its technical description for civil use is well publicized. At a recent ICAO FANS meeting the USSR unveiled the technical characteristics of their own Global Navigation Satellite System (GLONASS) and indicated that it would also be available for civil use by other countries. Similar to GPS, GLONASS was described as a system of 24 satellites, in three near circular, 19,000 km orbital planes. Nine satellites, five of which were operationally active, were in orbit in April 1988. By 1989-90, between 10 and 12 satellites will be in orbit with full deployment of GLONASS scheduled for 1991-95. Of more significance, the Soviets indicated that compatibility of GLONASS and GPS and any similar system should be "no problem".

Since civil aviation international standardization is vital for the implementation of new systems, the potential of insuring compatibility of the respective GPS and GLONASS systems promises significant benefits for worldwide civil applications. It signals to the international community that the development of common approach providing for standardized equipment and

use will allow for a worldwide, highly accurate, reliable navigation system. This is especially beneficial, both economically and operationally, in those parts of the world where there is no existing land-based navigation system.

Given that the research and development of both GPS and GLONASS is reportedly complete, the cooperative endeavors between the US and USSR civil aviation specialists would focus on taking advantage of the existing signals in space. Compatible systems would provide synergistic benefits in the areas of civil coverage and integrity monitoring. Specifically, these benefits equate to redundant coverage and receiver autonomous integrity monitoring (RAIM). The RAIM for nonprecision approaches is only possible when six or more satellites are available. This cannot be completely assured with a 21+3 GPS or 24 GLONASS satellite constellation. But if the signals from the two systems can be exploited by the user equipment, then there would be information available from 48 satellites and RAIM would be possible.

However, GPS and GLONASS are expected to be operational in the early 1990s and if expected benefits are to be obtained, then civil avionics specifications and standards must be established soon. This process, to insure compatibility of the systems, will require close cooperation between the US and USSR civil aviation organizations.

SCOPE: The scope of the US FAA, USSR MCA, GPS-GLONASS cooperative effort is limited to exploiting the r.f. signals from both the GPS and GLONASS satellite systems for civil navigation and positioning determination. It will include determining the civil capabilities of the respective satellite systems and the possibilities of compatible user equipment standards (avionics). If overall improvements in the safety level and usefulness of GPS/GLONASS is probable, the US/USSR cooperative effort will result in signal standards and minimum operational performance standards for user equipment (avionics) available for international use. With this goal in mind, working level discussions will be led by FAA technically oriented spokesmen with knowledge of civil GPS performance and operational characteristics. Since GPS was designed as a DOD system, a DOD technical representative will be available to assist the FAA spokesmen in all discussions with the USSR. Having a DOD representative on hand as a technical advisor will reduce the possibility of misinformation.

US/USSR COOPERATIVE ACTIVITIES: In order to determine the probability of overall improvements in the safety level and usefulness of the GPS/GLONASS systems, the following cooperative program should be conducted under the auspices of the

**Transportation Agreement as part of the Civil Aviation
Satellite/Spectrum Engineering Subgroup:**

1. Determine the performance and signal characteristics of GPS and GLONASS.
 - a. Examine civil performance accuracies
 - b. Examine civil signal structure
2. Identify similarities and differences of the civil capabilities of GPS and GLONASS.
 - a. List common features
 - b. Determine differences (i.e. earth reference model, time reference, etc.)
 - c. Identify and resolve significant issues
3. Assess the operational applications and merits of GPS/GLONASS avionics options.
 - a. Determine avionics options
 - b. Select specific avionics options for further evaluation
- 4.* Independently validate operational capabilities of selected avionics options based on a mutually agreeable test plan.
5. Develop performance characteristics and standards for civil GPS/GLONASS avionics/user equipment (i.e. minimum operational performance standards).
6. Recommend the GPS/GLONASS avionics/user equipment technical standards for civil use worldwide.

CONCLUSION: The availability of the GPS and GLONASS systems for civil aviation applications promises significant benefits to the international community. The recently signed Transportation Agreement offers additional opportunity to establish international performance standards for civil aviation use of the respective GPS/GLONASS systems. This cooperation will not compromise either national security interests or production techniques, but rather will be directed at improving the safety levels and usefulness of the respective systems by insuring their civil compatibility.

- * Prototype equipment will be built and tested independently to demonstrate the feasibility and maturity of the specifications of the developed GPS/GLONASS standards and minimum operational performance standards. No design specifications of the experimental avionics will be discussed or exchanged.

Appendix 2

The Modernization of the U.S. National Airspace System and the Transition to New Technologies

A speech presented by the
FAA at the AUSRIRE Technical
Symposium, Leningrad, U.S.S.R.

May 25-29, 1987

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THE MODERNIZATION OF THE U.S. NATIONAL AIRSPACE SYSTEM
AND THE TRANSITION TO NEW TECHNOLOGIES

by

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for

AUSRIRE Technical Symposium

Leningrad, U.S.S.R.

May 25-29, 1987

I have been asked to speak to you about the modernization of our U.S. National Airspace System and the introduction of new technologies into that system, particularly with respect to air traffic control surveillance. I would like to concentrate on the always difficult problem of transition from current technologies to new ones in our gigantic aviation system in which the many kinds of participants, the necessity for agreement, and the ever-present need to contain costs invariably force us into slow evolutionary change.

All of you, I am sure, are aware of the major modernization underway in the U.S. system--the National Airspace System (NAS) Plan. It will provide us with a modern, well-integrated system of services and facilities to meet the challenges of a growing aviation system. At the end of our U.S. modernization, in addition to the upgrading of the facilities themselves, we see that:

- o The air traffic control process, through the Advanced Automation System, will be far more flexible, and more automatic, than it is today and will be far along to permitting automatic creation and transmission of conflict-free clearances.
- o Information available on weather and winds will be improved dramatically.

- o Information flow will be enhanced through use of digital data link communications.
- o Dynamic knowledge of system capacity and airport capacity will have become good enough to permit a great deal more strategic planning than exists in the system today, and the system will be more capable of rapid, dynamic adaptation as the situation changes.
- o Cockpit systems will simplify and optimize the interaction of pilots with automatic systems and digital communications devices.

But this is surely not the end of the road. Our aviation community believes that there are other challenges, as described by the Radio Technical Commission for Aeronautics (RTCA) Special Committee 155, "User Requirements for Future Communications, Navigation, and Surveillance Systems, Including Space Applications." They are the following:

1. lack of sufficient airport and heliport facilities in major city areas,
2. lack of surveillance information in much of the airspace over oceans and unpopulated areas,
3. lack of instrument approach capability to many paved and lighted airports, and, perhaps most important,
4. lack of low-altitude communication, navigation, and surveillance (CNS) coverage in most areas of the world.

The growing view is that the most effective way to reduce or eliminate some of these system deficiencies is through the use of satellites as a way of gathering information and improving the information flow, which is the key to aviation system improvement.

When the National Airspace System (NAS) Plan was first announced, many people commented that it did not emphasize satellites enough. The Plan was based on the idea that the modernization must be one of low technical risk. Yet we knew, even as the NAS Plan was being developed, that we were in the midst of a revolution of communications technology, of computer and data processing technology, and we knew that satellite capabilities would come on the scene and would, with luck, become reasonable in cost. From the start it was recognized that the NAS Plan would need to be designed to cater to that future.

Does the commitment to our present modernization stifle the timely introduction of beneficial new technology? We think it does not. Instead, the manner in which the modernized system is designed makes it the essential foundation for the introduction of new technologies--communications, computers, and, yes, satellite applications.

It was only a year after the publication of the NAS Plan that the FAA Administrator challenged our aviation community to explore and exploit the beneficial use of new technologies including, prominently, satellites. After all, FAA had been involved in satellite applications for aviation since the early 1960's. The first practical application trial, the use of satellites for air traffic control air/ground communications, dates back to 1964, when FAA worked with the Air Transport Association of American and Pan American World Airways in a pioneering experiment. A large number of studies, developments, analyses, and tests have been conducted in the intervening years, not only by FAA, but also by the National Aeronautics and Space Administration and by the industry.

Until very recently, virtually all of the studies showed that satellite applications to air traffic control were technically feasible and could yield benefits, but cost projections were so high that the aviation community was not motivated to move forward. We think that situation has changed and that we will, indeed, soon see the great potential of satellite services to civil aviation begin to be realized. We think satellites are likely to play an important role in the improvement of air traffic services around the world.

It also came to be recognized by many countries that the new technologies would challenge the world to cooperate more in the provision of services, because of the characteristics of coverage of satellite services and the need to have international agreement and standards for their application. That need is far greater in the application of satellite technologies, for example, than in air traffic control data processing which can readily be applied within a country.

Through agreement and cooperation of a number of countries, including eminently the U.S.S.R. and the United States, the Future Air Navigation Systems (FANS) Committee was formed in the International Civil Aviation Organization (ICAO) to cope with the issues of the future system.

I said a moment ago that the NAS Plan modernization in the United States, and others like it in other parts of the world, form the essential foundation for the new capabilities and are in no way roadblocks to progress. Let me explain. It is sometimes asserted by enthusiastic advocates that satellites and the other new technologies might be used instead of the automation of the air traffic control system and its improvement. I believe that view misses the point. While satellite communications, surveillance, and navigation all improve the information flow between aircraft and the Air Traffic Control system and permit the air traffic control process to be made more efficient, they are not the Air Traffic Control system, but only tools which the system can use beneficially. (Fig. 1)

The Air Traffic Control System is that combination of controllers, procedures, automation and computers, interfacility communications, and flow management needed to provide the service. It is the heart of the system. The things I've been talking about--air/ground communications improvements, navigation services, radar, secondary radar, and satellite surveillance--are the mouths, the eyes and ears. Recognizing this, we can introduce new services without wasting the investment we are making in the heart of the system. Perhaps even more important, it is possible to introduce new services, such as the satellite services, when and where there is a broad recognition of need and when the costs and benefits justify the transition.

With this background, FAA last year developed its vision--its snapshot in time--of the future communications, navigation, and surveillance (CNS) system. This vision of the future system represents the broad views of FAA and reflects the work done by the RTCA Special Committee 155 activity. We offered this view to the ICAO FANS Committee at FANS-3 last November, and were pleased that there is a remarkable coherence of views among the members of the FANS Committee. An important contribution was made at FANS-3 by the U.S.S.R. in FANS Working Paper 90, "Conception and Stages in the Construction of a Global Satellite-Based System for Communications, Navigation, and Surveillance."

From our perspective, the new CNS capabilities must be judged against an air traffic control environment of the future with the following characteristics:

Operators will always wish to retain and increase their freedom to fly where and when they wish. However, traffic density will be so high that traffic management will be required in more airspace as traffic grows. As aircraft enter higher traffic density airspace, they will automatically become part of the controlled system and fit into the managed terminal area and airport situation. Visual Flight Rule (VFR) operations will remain viable, but enhanced to reduce collision risk by a technical system which, normally passive, will warn all aircraft of impending conflicts and will be able to intervene to avoid conflicts.

The system must have the capability to provide CNS services in essentially all airspace, from the surface to at least 70,000 feet for conventional aircraft and current supersonic aircraft, as well as to serve aircraft that may fly far higher and at far more demanding speeds. The requirements for failure protection will remain high in a new CNS system, but failure protection can be achieved, even while permitting simplifications in the existing avionics complement. Our guiding ground rule must be that no single element failure may deprive the system simultaneously of both navigation and surveillance.

satellite navigation system envisaged by ICAO FANS comes into being, ADS service will be improved by the high accuracy and integrity achievable from such a system, and by the significant benefits to be achieved by the use of a common position determination standard.

The question which faces us is whether such a navigation-based automatic dependent surveillance service can do more--whether it can play a role in high-density airspace as well. No matter how good it is or becomes, automatic dependent surveillance will always be dependent on the aircraft navigation system. We lose a degree of independence between navigation and surveillance, which we have long held as important. We have concluded, as has FANS and RTCA, that automatic dependent surveillance will be a powerful tool and will get more powerful as we gain confidence in it, and as the navigation information which is its basis becomes better and more uniform across the system.

We believe that in lower density terminal airspace, automatic dependent surveillance can be a valuable tool and may become a perfectly acceptable, less expensive substitute for primary and, in the long run, secondary radar. It may have useful applications as a back-up and possibly as a primary surveillance system in high-density areas as well. It offers the opportunity of high update rate--higher than most radars in common use. Given the expected capabilities of satellite navigation systems, it may achieve accuracies approaching, and in some cases even exceeding, those of currently used primary and secondary radar--perhaps even accurate enough to serve as the data source for collision avoidance if aircraft regularly transmit their navigation position of the moment. But there may be a cross-over point when satellite surveillance may not be cost-effective in high-density areas, where the ranges of concern are limited, perhaps 50-150 miles, and where the number of aircraft and the communications load is very high. It may be more sensible there to use terrestrial systems--systems like secondary surveillance radar, especially Mode S and its data link.

We have some concern that automatic dependent surveillance with its inherent dependency may not be fully acceptable to aircraft operators and

administrations, and that cooperative independent surveillance by satellite is an attractive possibility. The FANS satellite communications system architecture and system structure take this possibility into account and provide the capability to permit cooperative independent surveillance using two or more satellites. The most practical and perhaps the most cost-effective way would be to use communications satellites of opportunity to provide two-dimensional cooperative independent surveillance using aircraft altitude as an input. This is less than perfect, but may be an acceptable way to go in the future as altimetry itself improves and as barometric altimetry may become augmented with satellite height cross-check. The cost, of course, will be higher than for communications and ADS alone because additional satellites will be required to assure continuity of service.

There is yet another dimension to the surveillance matter. At a few airports around, the world traffic is so high and the need for surface air traffic control will be so compelling that airport surface guidance and control systems will need to be implemented. While satellites may be able to provide this service, terrestrially-based systems may be powerful competition to enhance the primary radar for surface detection equipments now in use and going into the field. Multilateration schemes using secondary surveillance radar technology have been developed and can do that job well, especially as SSR Mode S and its data link comes into wide use.

Limiting the Avionics Complement

A further consideration in choosing the proper balance between space-based and terrestrially-based systems is the avionics complement of the future. So far we have talked about satellite communications equipment, satellite navigation equipment, a Mode S system with its data link, and possibly surface guidance equipment. Add to that the MLS, which undoubtedly will come into wide use, the inertial systems which will continue to be carried on many aircraft, VHF communications, and VOR/DME.

In a new system for the future we need to think carefully about how we can reduce that complement of avionics. Perhaps the first place to look is at the several data links--the SSR Mode S data link and the satellite data link. The

concept of open-system interconnection can ease the pain of carrying both of those systems, but a better answer for the long-term might be to use the satellite system architecture and its data link structure to form the foundation of a system in which the same avionics unit might be used for satellite communications and terrestrial communications, as well as to meet the communications and data link demands of airport surface surveillance guidance and control. If this is the direction we choose to go, then we must look eventually to new and different L-band based terrestrial system elements to permit the least costly avionics suite.

In our look at user equipment requirements in a world where automatic dependent surveillance is the principal surveillance system, the minimum airborne avionics complement would be two suitable navigation receivers/processors and one communications transceiver processor to satisfy the ground rule that no single system element failure may simultaneously eliminate the capability for cockpit navigation and ATC surveillance. (It is assumed that the independent airborne collision avoidance system might be used by some, and MLS would be required if precision approach and landing guidance is desired in the aircraft.) In a cooperative independent surveillance world, the minimum complement would be one suitable navigation receiver/processor (two in airspace where cooperative independent surveillance is not available) and one combined communications/surveillance unit which contains the L-band communications transceiver/processor for voice and data communications, and receives, processes, and transmits the surveillance ranging signals. {Altitude reports must be included in the aircraft transmission.} {The communications and surveillance units may also be provided separately.} (MLS and collision avoidance systems would again be needed on the same basis as above.)

In these two future scenarios, terrestrial systems would have evolved to be fully technically compatible with the satellite architecture and it is assumed that Mode S and its data link, VOR/DME, and VHF communications would have been supplanted. That is a far away scenario, of course, but it is a consequence of striving for the minimum avionics complement.

The Future of Primary Radar

There is a final issue which we must confront in the nearer term--the future of primary radar for air traffic control surveillance. It is often said that secondary surveillance radar has become the principal surveillance element by the way we use it, and there are administrations and places where secondary surveillance radar is used exclusively, without primary radar. As we move along in our system modernization, the question of whether a new generation of primary radars is required for air traffic control begins to loom large. It is an expensive system and we need to look carefully as to whether its continuation as part of the ATC system can be justified for air traffic control, noting, of course, that radars for other purposes including weather detection will continue to be with us.

Given a combination of satellite-based automatic dependent or cooperative independent surveillance complemented by terrestrial systems, initially SSR Mode S, the justification for primary radar becomes ever more problematical. All the old issues (such as airborne equipment, radio failure, and the small number of aircraft which choose not to cooperate with the air traffic control system) remain with us, and there are people who still are convinced that primary radar is somehow better and of higher integrity than secondary radar or satellite surveillance. I believe time will prove that secondary radar, such as the SSR Mode S system and its data link, and satellite surveillance and communications systems will prove to be of high integrity and that the justification of primary radar for air traffic control may fade away. It is a matter to be considered carefully before we embark on yet another major investment in primary ATC surveillance radar.

As we go forward in our studies and as we develop our inputs into the final work of ICAO PANS, we need to confront these issues and reach operationally acceptable decisions. Based on what we know now, assessment and development might well proceed along the following lines:

- a. The development and operational demonstration of automatic dependent surveillance using satellites, as well as terrestrial systems where appropriate, to establish its actual capabilities in service, not only over oceans but in domestic airspace as well.

- b. While automatic dependent surveillance will no doubt begin with the navigation capabilities now available in aircraft, we need to strive to transition to the uniform use of the global satellite navigation system we all agree will come.
- c. We need to continue to explore the potential of satellite cooperative independent surveillance schemes to assure that the agreed ICAO satellite architecture lays no road blocks in the way, and we should assess the best of a variety of ways of achieving such satellite-based cooperative independent surveillance. While we need to examine satellite-based cooperative independent surveillance systems which provide three-dimensional surveillance information, it may be possible at an early date to conclude that the costs and benefits of a two-dimensional system, which requires altitude input from the aircraft system, may be a satisfactory lower cost solution.
- d. We need to explore the requirements for, and the long-term impact of, a transition to satellite-compatible L-band terrestrial systems, not only for surface surveillance guidance and control, but also in the distant future to replace the VHF communications system and the VOR/DME, to establish clearly the impact of such a decision on total system costs and on the eventual goal of simplifying the aircraft avionics complement.
- e. Perhaps most important in the near term is the need to assess once more the continued value of expensive primary radar for air traffic control. Perhaps the time has come when the aviation community can say that this major expenditure is no longer worthwhile.

There is much work to do. As always we can't be sure we're on the right path. It is not possible for us to foresee the impact of inventions yet uninvented or the breakthroughs yet to come. Transitions will always be difficult, but the shape of the future CNS system is becoming less cloudy.

As I noted, we are considering, as is FANS, concepts which could eventually permit the elimination of a variety of current systems including VOR/DME, primary radar, and possibly secondary radar in all but the high-density terminal areas, to substitute L-band voice and data communications for existing VHF and HF communications, and the eventual removal of other navigation systems such as Loran-C and Omega. It is a large mouthful.

Decisions to withdraw systems, or decisions on whether systems can be removed, are far beyond the realm of engineers. The problems of transition and the timing of withdrawal of existing systems will depend on the demonstrated capability and implementation of the new systems. A clear and compelling case for transition to the new systems will ~~include~~ ^{require} consideration of the benefits perceived by the aviation community, the perceived need for retention of present systems by various elements, and, of course, the willingness of governments and users to continue financing eventually-redundant systems. Considering the rewards to be derived, it is none too soon to look seriously at these issues. Most of them are world issues, not just those of the U.S. or the U.S.S.R., and we will need to find international solutions.

<i>Supporting Services</i>
Air/Ground Communications Navigation Services Radar/Secondary Radar

**The Sensors:
Eyes & Ears**

<i>Air Traffic Control</i>
Controllers Procedures Automation/Computers Interfacility Communications Flow Management

**The Air Traffic
Control System**

Appendix 3
FAA GPS PROGRAM MANAGER
WORKING PAPER

FOR OFFICIAL USE ONLY

Any discussion of the use of the United States of America's Department of Defense (DOD) Global Positioning System (GPS) by civil aviation, needs to start with a review of our understanding of navigation. Navigation simply put is "the process of planning, recording, and controlling the movement of a craft or vehicle from one place to another." This quote is from the Federal Radionavigation Plan (FRP) as are the following:

"Radionavigation--The determination of position, or the obtaining of information relating to position, for the purposes of navigation by means of the propagation properties of radio waves.

Radiodetermination--The determination of position, or the obtaining of information relating to positions, by means of the propagation properties of radio waves.

Radiolocation--Radiodetermination used for purposes other than those of radionavigation.

Area Navigation (RNAV)--A method of navigation that permits aircraft operations on any desired course within the coverage of station-referenced navigation signals or within the limits of self-contained system capability."

To conclude our review of navigation, especially aviation navigation, we must remember that "aircraft navigation is the process of conducting aircraft from one place to another and includes position determination, establishment of

course and distance to the desired destination, and determination of deviation from the desired track. Requirements for navigational performance are dictated by the phase of flight operations and their relationship to terrain, to other aircraft, and to the air traffic control process."

Starting with this review of aviation navigation, a short review of the GPS system is also required before a discussion of GPS and aviation use can be undertaken. The following information is from DOD and RTCA documents.

GPS is an DOD operated, global coverage, very accurate radiodetermination system suitable for radionavigation, radiolocation, and time transfer. It provides two levels of service, the standard positioning service (SPS) and the precision positioning service (PPS). Only the SPS is available to the general public and is the only service considered in this paper. Basically GPS is composed of three segments: Space Segment, Control Segment, and User Segment. While only the signal-in-space from the satellite is of concern to the civil user, it is worthwhile to have some knowledge of the overall system.

The Control Segment is responsible for maintaining GPS. It includes five monitor stations and three ground antenna sites located throughout the world and a master control station. The monitor stations passively track all satellites in view thus obtaining ranging data from the satellite signals.

This information from each monitor station is provided to the master control station where it is used to determine satellite orbit, updates for the navigation message of each satellite, and other satellite housekeeping functions. This new control information is then uplinked to the satellites from the ground antenna.

The Space Segment is the satellites and the constellation they are in. Currently the DOD announced plans are for a constellation of 24-satellites, 21 operational satellites with 3 in-orbit operational spares, in one of 2 configurations. Either constellation configuration seems suitable for civil aviation although complete analysis has not been completed. The present schedule is to have 21 satellites in orbit and operational sometime in 1992 with the full constellation of 24 satellites in orbit during the mid-1990's . At that time the probability of having the 21 satellites in orbit, which is required for worldwide/global coverage, is at least 0.98.

The User Segment is the user equipment or for aviation the avionics. It receives the satellited-transmitted signal and may calculate the users' position, velocity, and time. The Radio Technical Commission for Aeronautics is now in the process of developing Minimum Operational Performance Standards (MOPS) for GPS avionics.

The GPS user equipment determines a position fix using ranging. The equipment determines the pseudo ranges from at least four satellites and from the navigation message on the signal it obtains GPS system time, ephemeris

data for the particular satellite being tracked, almanac data for all satellites, satellites health, coefficients for the ionospheric delay model and coefficients to calculate Universal Time Coordinated (UTC). Using this information, and other stored data the equipment can calculate 3-D position, time, and velocity. The signal that will be used by civil aviation is the so called C/A code on the L₁ signal. The frequency of the L₁ signal is 1,575.42 MHz and the signal modulation is Pseudo Random Noise (PRN) Bi-Phase Shift Keying (BPSK) of the carrier frequency. The C/A code is a 1023 bit Gold code with a clock rate of 1.023 MHz. Each satellite has a unique Gold code assigned providing identity. The navigation message is superimposed on the code at a data rate of 50 bits/sec. It has 25 data pages with 1,500 bits in each page. Complete signal characteristics for GPS are in the United States Air Force document ICD-GPS-200.

Using this background information, a discussion of the role of GPS in civil aviation can be made. The FAA has been involved with the GPS program almost from its start. During the early days of the program it was determined that if GPS was going to be used in the National Airspace System then it should be as good as or better than what is now providing aviation navigation. The first step was to determine what aviation requirements are for navigation. The current requirements are contained in the latest edition of the Federal Radionavigation Plan but they continue to evolve. These requirements include such objective items as accuracy, coverage, reliability/availability, and integrity and subjective items such as user/air traffic service acceptance,

cost acceptance, and institutional issues. Then values for these items had to be established for each phase of flight; nonprecision approach, terminal, domestic en route, special and remote areas, and oceanic. Another consideration for establishing requirements is how the system is to be used. Is it to be a supplemental system, a sole-means system when used with another supplemental system or a sole-means system to replace VORTAC, NDB, OMEGA, and LORAN-C. A comparison between these established performance requirements and the expected performance of the GPS SPS was made. At first there were many differences including accuracy, coverage, and integrity. Cooperation between DOD and the FAA has resolved the accuracy issue at 100 m 2 drms and coverage and reliability issue with a 24-satellite constellation. However, the integrity issue, which is a civil aviation requirement only, is still to be resolved.

The goal of the FAAs GPS program now is to prepare for the use of GPS in the NAS as a supplemental system as soon as DOD announces that GPS is operational and then be prepared to approve GPS alone or as part of a mix for sole-means aviation use when all 24-satellites are operational. In order to achieve this goal several activities have to be accomplished. These include: preparation and approval of a National Aviation Standard for GPS, development of a Minimum Operational Performance Standard (MOPS) and Technical Standard Order (TSO) for GPS, an Advisory Circular (AC) for GPS like the current ones for other RNAV systems, resolution of the GPS integrity issue, and development of NOTAM procedures. The one item in this list that controls all the others is integrity.

Integrity in the way used here means that the system can not provide the pilot with false (erroneous) information, or if it does then it must notify the pilot that the information is outside of tolerance. The current practice in aviation for navigation is to have an external monitor for each signal source and when the monitor detects the signal is out of tolerance the source is turned off within a limited time. For the current VORTAC the time from detection of an out of tolerance condition to shut off is 6 seconds. GPS as it is now planned to be implemented does not have this capability. Although self checks in the satellites do detect certain major malfunctions and make the signal unusable, GPS relies on the Ground Segment to detect and report or correct small out of tolerance conditions. This process can take up to 20 minutes or more before the situation is corrected or the user notified. This is not suitable for an aviation safety service such as navigation.

RTCA Special Committee 159 has established values for integrity. These values are:

	Oceanic	Domestic	Terminal	Nonprecision
	En Route	En Route	Area	Approach
Present Requirements				
Alarm Limit	12.6 nm	1.5 nm	1.1 nm	0.3 nm
Time to Alarm	120 sec	60 sec	15 sec	10 sec
Goal				
Alarm Limit	5,000 m	1,000 m	500 m	100 m
Time to Alarm	30 sec	30 sec	10 sec	6 sec

The FAA has not agreed to these values yet but RTCA developed them using information from FAA documents. Integrity work in the FAA has been on providing suitable integrity for nonprecision approaches and the criteria most often used is that the pilot must be notified within 15 seconds from the time the system accuracy performance is beyond 100 m. This is not an easy criteria to meet. Part of the problem is determining when the system performance is outside of tolerance. Position determination is dependent on the pseudo range from at least 4 satellites and the geometry of the user and the satellites. This implies that the best method for achieving suitable integrity would be for the user equipment to measure the system performance. Work done to date has shown that if there are at least 5 satellites in view with good geometry and if only one of the satellites is out of tolerance and the geometry is such that it causes a position error then the user equipment can detect there is an error. However, it takes one more good satellite with good geometry to isolate the bad satellite pseudo range and allow the navigation function to be used. While the 21-operational satellites with 3 operational-on-orbit spares constellation provides adequate redundancy for worldwide coverage, it is not suitable for nonprecision approach integrity.

The FAA has chosen to proceed with a ground-monitoring system with a ground-satellite-aircraft data link warning system. This concept will detect and isolate all out of tolerance conditions and prevent the use of a "bad" satellite in determining a navigation solution. Although this approach will cost the government more and will prevent the use of some satellites when the position error may still be within 100 m, it is fail safe and sure.

Another method that is being investigated to resolve the GPS integrity issue is to use the inputs from other navigation systems. Some aiding systems such as barometric altitude, very accurate time, and inertial navigation have been investigated and do help but do not completely resolve the issue. Two other navigation systems that show more promise are LORAN-C and GLONASS. Both of these systems add redundant coverage and position solutions which would allow integrity monitoring in the user equipment. LORAN-C coverage is limited to where there are transmitter stations but GLONASS is worldwide like GPS. This work has just started.

The choice of the method for insuring GPS integrity in aviation impacts the National Aviation Standard, MOPS and TSO, and the RAAV GPS Advisory Circular. This is just one example of the activities that must be accomplished to incorporate the use of GPS into the NAS.

It is the intent of the FAA to have all the mechanisms completed and in place such that civil aviation can use GPS as a supplemental system in the NAS when DOD approves GPS as operational. It is also the intent of the FAA to have GPS become a sole-means civil aviation system as soon as possible.

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Appendix 4

Pentagon Operations Directorate

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PENTAGON
OPERATIONS DIRECTORATE

PRIORITY

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GPS

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TO RUEOAWA/HQ AFSC ANDREWS AFB MD//SD/SDS//

INFO RUWJEB/SD LAAFS CA//CV/CW/C//CWN/CLR/CWNZ//

RUWTNOA/HQ AFSPACECOM PETERSON AFB CO//XP/DO//

RUVESLA/USSPACECOM PETERSON AFB CO//J5//

RUCUAAA/HQ SAC OFFUTT AFB NE//XP//

RHDIAAA/HQ TAC LANGLEY AFB VA//DR//

RUEAHQA/HQ USAF WASHINGTON DC//XOX/XOO/PRP/XOXFD/XOORF//

ZEN/SAF WASHINGTON DC//AQSS//

MAR 1988 19 20

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SUBJECT: GPS SATELLITE CONSTELLATION

1. THE AIR FORCE HAS RECEIVED A REQUEST FROM THE JOINT REQUIREMENTS OVERSIGHT COUNCIL TO IMPLEMENT A 24-SATELLITE NAVSTAR GLOBAL POSITIONING SYSTEM (GPS) CONSTELLATION WHICH WOULD PROVIDE COMPLETE AND CONTINUOUS COVERAGE TO THE OPERATIONAL GPS USER COMMUNITY. IN RESPONSE TO THE USER REQUIREMENT, THE AIR FORCE WILL MODIFY GPS DEPLOYMENT AND REPLENISHMENT SCHEDULES AND THE ON-ORBIT CONSTELLATION CONFIGURATION TO ACHIEVE AN OPTIMUM 21-SATELLITE CONSTELLATION PLUS 3 ON-ORBIT, OPERATING SPARES AS SOON AS PRACTICABLE.

2. REQUEST AFSC REVISE THE PLANNED GPS LAUNCH AND REPLENISHMENT RATE THROUGH BLOCK IIR TO THE FOLLOWING PROFILE: FY 89 - 6; FY 90 - 6; FY 91 - 6; FY 92 - 4; FY 93 - 4; FY 94 - 2; FY 95 - 1; FY 96 - 3; FY 97 - 3; FY 98 - 4; FY 99 - 4; FY 00 - 4; FY 01 - 1. FY 2001 REFLECTS ONLY ONE SATELLITE BECAUSE OF THE LIMITATION OF THE 20-SATELLITE BLOCK IIR BUY. YOU SHOULD PLAN TO PROCURE SUBSEQUENT REPLENISHMENT SATELLITES AT A RATE WHICH WILL SUSTAIN THE 21+3 CONSTELLATION THROUGH THE LIFE OF THE SYSTEM

3. THE OPPORTUNITY TO IMPLEMENT THE LARGER CONSTELLATION DEPENDS PRIMARILY ON THE PERFORMANCES OF THE OPERATIONAL BLOCK II SATELLITES AND ON THE DELTA II BOOSTER. WITH THE ABOVE LAUNCH RATE, A SYSTEM PERFORMANCE INCREASE OF APPROXIMATELY FIFTY PERCENT WILL ASSURE GPS AVAILABILITY TO MEET THE VALIDATED REQUIREMENTS IN THE EARLY 1990'S.

4. THE GPS PROGRAM MANAGEMENT DIRECTIVE WILL BE REVISED TO REFLECT THE NEW BASELINE CONSTELLATION. POINT OF CONTACT IS MAJ JULES MCNEFF, SAF/AQSS, AV 223-3293. BT

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TAD=88089/1811Z

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